

# **Airborne Hyperspectral Remote Sensing at LEO-15**

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## **LONG-TERM GOALS**

Visible radiation is the only electromagnetic tool that directly probes the water column, and so is important to Naval systems for bathymetry, mine hunting, submarine detection, and submerged hazard detection. Hyperspectral imaging systems show great promise for meeting Naval imaging requirements in the littoral ocean. Hyperspectral imagers should also improve beach egress zone characterization, terrain categorization, trafficability and the identification of on-shore vegetation and soil types. To support the development of these applications and to test design features for the Coastal Ocean Imaging Spectrometer (COIS) to be flown on the Naval Earth Map Observer (NEMO) spacecraft (Wilson and Davis, 1998, 1999) we have designed and built the Ocean PHILLS instrument. The overall goal is to demonstrate the utility of airborne and spaceborne hyperspectral imaging for the characterization of the littoral zone and to develop algorithms for use with data from NEMO and other future systems.

## **OBJECTIVES**

This report summarizes progress to date regarding the field campaign at LEO-15 that took place during the 17-29 July 2000 time period. The objective is to correlate the hyperspectral imagery with detailed in-situ measurements and to use the combined data set to develop algorithms for characterization of the coastal ocean and the on-shore environments using hyperspectral data.

## **APPROACH**

The Ocean Portable Hyperspectral Imager for Low-Light Spectroscopy (Ocean PHILLS) is a push-broom hyperspectral imager specifically designed for imaging the coastal ocean (Davis, et al., 1999). It uses a backside illuminated CCD for high sensitivity, and a newly designed all-reflective spectrograph with a convex grating in an Offner configuration. This configuration leads to very low spectral smile and keystone distortion. It images in 64, 128 or 512 spectral bands over the range 400 to 1000 nm. Data is collected for 1000 pixels across track. The ground sampling distance (GSD) is determined by the sensor foreoptics, frame rate and aircraft speed and a large range is possible. The swath width, pixel size and spectral resolution are selected to suit the needs of the particular mission. An image is constructed by "pushing" the sensor across-track field-of-regard along a pre-determined flight track.

The data were examined in the field to assure that quality data were collected. Quick look images were prepared to share with the other investigators, often within one day of data collection. Based on pre-LEO-15 laboratory sensor calibration, RGB images of individual data runs have been generated and posted on our web site ([www-rsd.nrl.navy.mil/7212](http://www-rsd.nrl.navy.mil/7212)).

## **LEO-15 WORK COMPLETED**

The Ocean PHILLS instrument was used during 17-29 July 2000 at the LEO-15 site offshore from Tuckerton, NJ. The study area consisted of Great Bay and surrounding marsh and the traditional offshore in-water survey region of the LEO-15 study site (see Figure 2, below, and the LEO-15 links at the HyCODE web site <http://www.opl.ucsd.edu/hycode/html>). Our group had 3 objectives going into the field experiment. One objective was to collect moderate 3-10 m spatial resolution hyperspectral images of the mouth and interior of Great Bay coincident with ground truth in-water measurements in order to validate suspended sediment algorithms in the absence of a detectable bottom signature and to develop new algorithms when the bottom signature was present. This objective was done in collaboration with Bob Arnone and his group at NRL-Stennis. A second objective (done in collaboration with Rick Lathrop of Rutgers University) was to collect high (1.25 m) spatial resolution images of the surrounding marsh coincident with ground truth ASD measurements to address marsh classification and trafficability issues. The third objective was to provide aerial support to the in-water studies taking place in the traditional LEO-15 offshore study area. This objective primarily involved interaction with Oscar Schofield and Scott Glenn of Rutgers University.

This experiment was plagued by heavy rain and cloudy weather for most of the two week time period. However, good data were collected on 17, 18, 21, 22 and 27 July. Information on the flight lines can be found either at our, or the official HyCODE, web site. The flight lines run at an azimuth angle of 100° or 260° depending if the flight took place at 9:00 - 10:30 am or 14:00 - 15:30 pm local time, respectively. The time of day was selected to achieve a solar zenith angle of about 40° - 55° in order to minimize sun glint. The flight azimuth direction minimizes differential lighting across the scene by flying directly toward or away from the Sun. The aircraft used was an Antonov AN-2 Soviet-design biplane, operated by Bosch Aerospace (<http://www.boschaero.com>). The aircraft is capable of sustained low speeds of 85-90 knots (45 m/s), ideal for maximizing signal level over dark water targets. The data was collected at 8,500 ft yielding 1.25/2.5 m pixels and a swath width of 1.25/2.5 km depending upon the sensor lens used. Lines were flown from east to west and extended to the east far enough to where the water becomes suitable for deep-water calibration.

At the start of each flight, two or three lines were flown using a narrow field-of-view sensor lens to cover regions at 1.25 m spatial resolution. These lines typically passed over Sheepshead Meadow, which was our target area for high spatial resolution marsh coverage. These lines also passed over Seven Island, which is where we had placed three calibration panels of known reflectance. Another three or so flight lines were assigned to cover Great Bay. The plan was to change to a wider field-of-view sensor lens in flight so that the Bay could be completely covered with no spatial gaps. This was attempted successfully on our first flight day (17 July), but the open plane environment caused some dust to deposit on the sensor slit. This can lead to reduced data quality. Rather than risk slit contamination, the sensor lens was not changed in flight again. Data collected the next day was taken with the wide field-of-view (2.5 m spatial resolution) lens, but all subsequent flights used the narrow field-of-view lens. To cover the LEO-15 offshore study area, two additional flight lines were typically assigned to cover that region. One line was constrained to pass over the LEO-15 optical Node A, while the other line was positioned as required.

At LEO-15 we initiated a practice of including a HyCODE scientist as part of the scientific flight team. Their primary job was to observe each flight line from the air noting items of scientific interest. Their enhanced insight into the physical or biological processes involved allowed us to effectively pre-screen the data for serendipitous items of scientific importance. Items of particular importance were radioed back to the LEO-15 control room to initiate additional in-water coordinated study. An example of this is discussed in the next section. A real-time video link between the plane and the LEO-15 control room was successfully operated on the last day of flight. This demonstration showed that scientists on the ground could participate in this real-time data interpretation process, and we plan to utilize this technological capability on all future LEO-15 flights.

## RESULTS

The primary result to date is good quality hyperspectral aerial data sets for the Great Bay, the surrounding marsh, and the traditional offshore LEO-15 study area. To date we have processed data taken on 21, 22 and 27 July 2000. Data taken on 17 and 18 July are currently being processed. RGB JPEG images of individual data runs have been generated and are posted on our web site. Information about each data run, and a graphic displaying the run in relationship to the LEO-15 area is also posted. Users can use these images to identify particular areas of interest and request data sets from us. We have recently resolved issues relating to our in-flight GPS system and can now accurately geo-reference most of the LEO-15 data (see Figure 1). Positional information relating to each image will soon be posted on our web site.

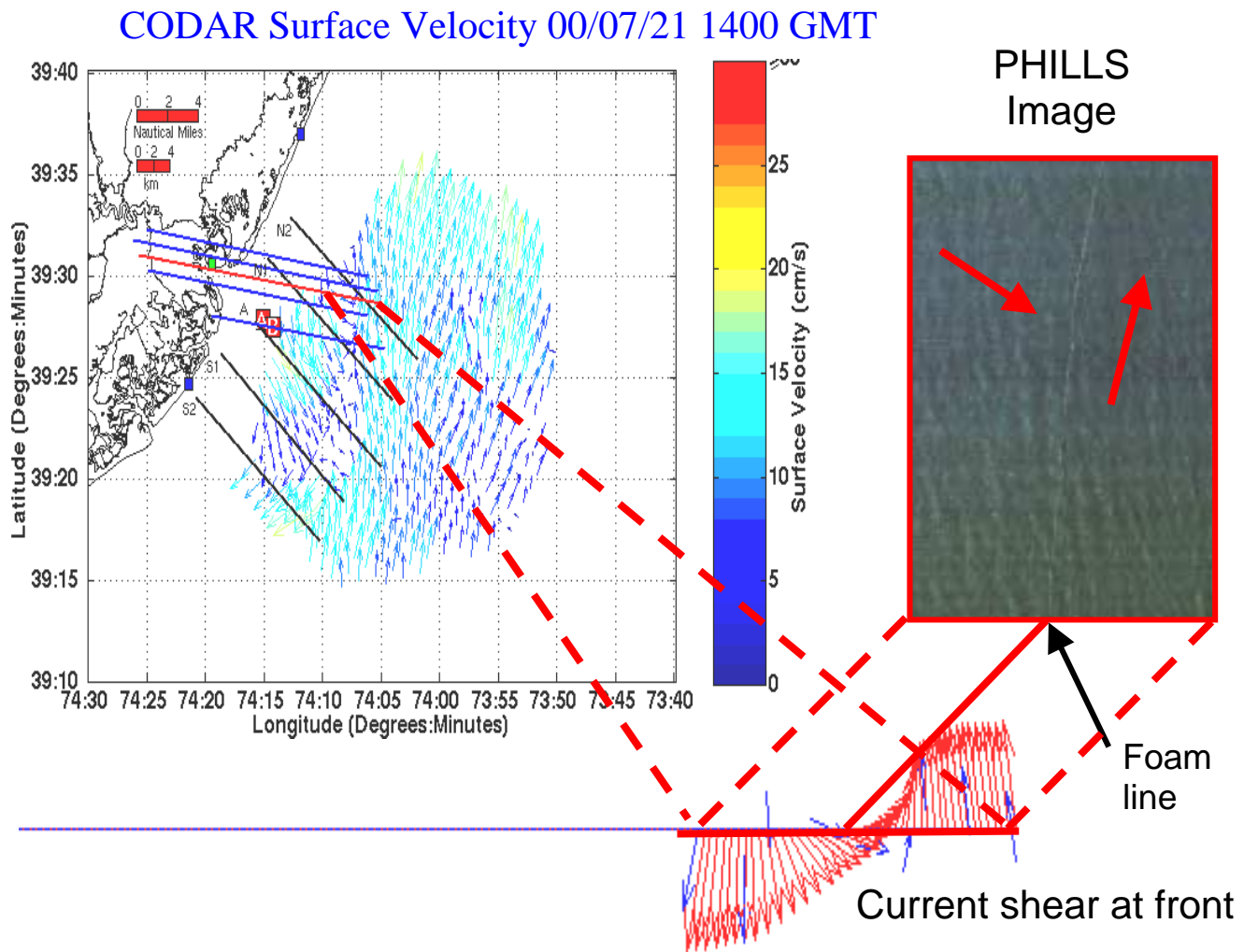


**Figure 1. The image on the left is a segment of data collected with the PHILLS sensor on 22 July 2000. Nonuniform plane motion is responsible for the distortion in the image. The image on the right has been geo-rectified with a commercial software package using GPS information collected during flight.**

The data now available have been calibrated using a pre-LEO-15 laboratory calibration. There are known problems with this calibration, and we are in the process of reviewing and refining the calibration before producing very accurate calibrated data sets for distribution to other LEO-15 participants. It is anticipated that the majority of the publications from this work will come from

collaborations with other participating scientists. The results discussed next highlight three of the studies that are currently underway.

On 21 July 2000 we collected simultaneous PHILLS hyperspectral data while John Kohut, John Fracassi and Scott Glenn (PI) at Rutgers University collected CODAR data (Figure 2). During the PHILLS collection we observed a narrow continuous foam line. Real-time analysis of the CODAR



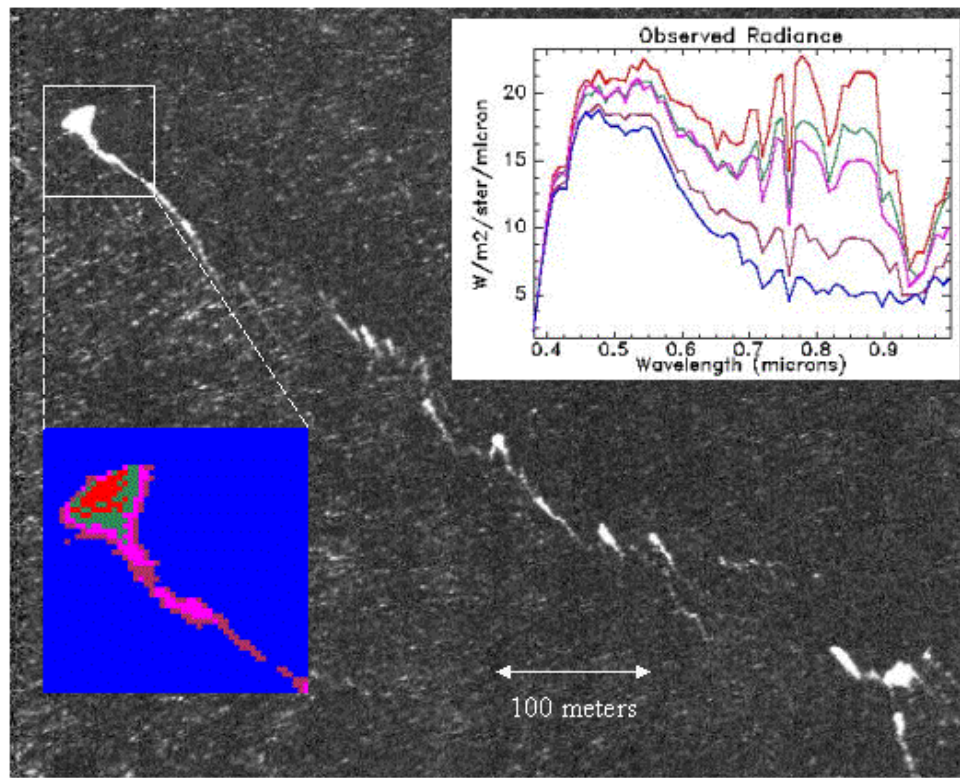
**Figure 2. A strong offshore foam line was observed during the PHILLS data collection. Analysis of the concurrent CODAR data showed a strong convergence at the location of the foam line.**

data showed that the foam line was associated with a strong current shear. Research ships were dispatched to study this feature in detail. Continual monitoring of the CODAR data showed that the current shear disappeared some hours later due to changes in tides and wind. The ship measurements confirmed this change and the coincident disappearance of the foam line. This real-time analysis of remote sensing data demonstrates the potential for real-time use of this data for Naval applications.

A Red Tide was observed from the aircraft on the following day (22 July). A segment of this data is shown in Figure 3. This particular scene is informally referred to as the “Red River”. The colored



## Red Tide Observed at 790 nm on 22 July 2000 With the PHILLS Sensor



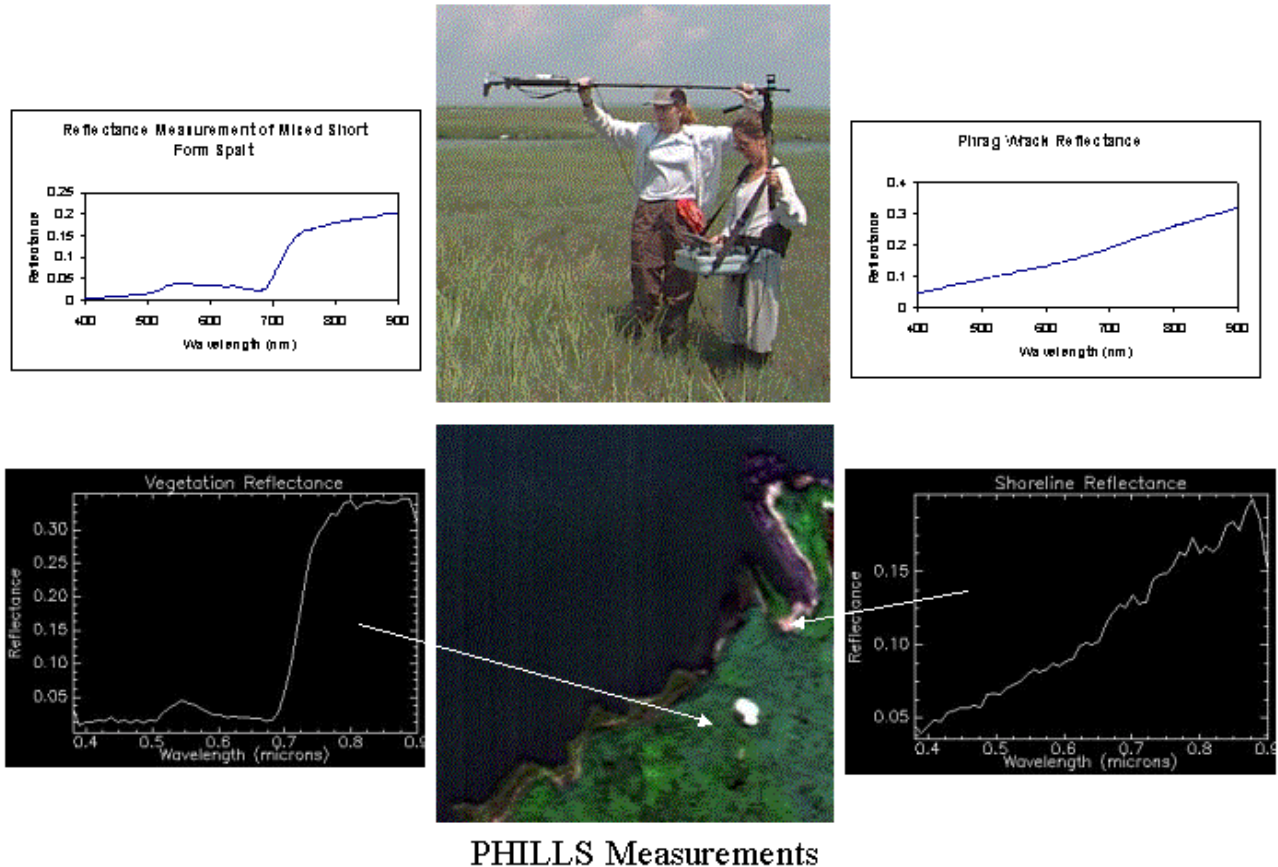
**Figure 3. A Red Tide was observed on 22 July 2000. The colored insert is the ratio of observed radiance at 790 nm divided by the observed radiance at 550 nm.**

insert at the head of the “river” is a ratio of the radiance observed at 790 nm to that observed at 550 nm. The observed radiance is the true water leaving radiance and surface reflected radiation convolved with the atmospheric transmission plus atmospheric scattered solar radiation. Observed radiance from each of the color-coded regions is also shown. The spectrum colored blue is the observed radiance for the non Red Tide water. For the other regions, their difference from the blue spectrum represents true changes in water leaving radiance convolved with the atmospheric transmission. A preliminary analysis suggests that much of the spectral change as a function of observed radiance is due to a change in surface brightness - that is more or less Red Tide material. A careful spectral analysis is required to de-convolve volume or surface emissive effects from possible varying depth effects.

In addition to the water related studies just described, our group is also involved with interpreting PHILLS data collected in the surrounding wetlands. On 21 July, ground truth reflectance measurements were made of the surrounding marsh (see Figure 4). The area studied is an estuarine inter-tidal emergent wetland, dominated by *spartina alterniflorous* and *spartina patens* grasses. Also shown in Figure 4 is a segment of a PHILLS image (taken on another date and at another place within the marsh) with some examples of derived reflectance spectra. The PHILLS reflectance spectra were derived from the calibration panels using the Empirical Line Method. Because of the broad atmospheric water vapor absorption band at 945 nm, the PHILLS reflectance should not be trusted

above 900 nm. Our ground truth measurements sampled about 20 different localized marsh conditions. In many of the spectra, reflectance differences are subtle. Sensors with only a few spectral bands would not be able to differentiate this difference. Our ground truth database should, however, form a good basis to classify the ground conditions noted in the PHILLS imagery.

### Ground Truth Measurements



### PHILLS Measurements

**Figure 4. Surface reflectance measurements were made of the marsh to help interpret PHILLS derived measurements.**

### IMPACT/APPLICATIONS

The Ocean PHILLS produces good quality spectral imagery of the coastal ocean. The data has very good sensitivity for coastal scenes as demonstrated at LEO-15 and other sites. A key to the utilization of this type of imagery will be the product algorithms verified with, or derived from, the LEO-15 data that will be applied for future Naval applications.

### TRANSITIONS

The Ocean PHILLS data will be shared with the HyCODE participants. When combined with their in-water data we anticipate jointly developing algorithms for shallow water bathymetry, the characterization of bottom types, and water column optical properties. Many of these algorithms will eventually be transitioned to NEMO and other DoD hyperspectral programs.

## RELATED PROJECTS

This effort is closely coordinated with the ONR Coastal Benthic Optical Properties (CoBOP) DRI (Mazel, 1998), the ONR Hyperspectral Coastal Ocean Dynamics Experiment (HyCODE) DRI and NRL Spectral Signatures of Optical Processes in the Littoral Zone (Spectral Signatures) ARI.

## ACKNOWLEDGEMENTS

The LEO-15 field campaign and continuing data processing and analysis was, and remains, possible because of the efforts of many individuals at NRL. All of the ground truth measurements and subsequent data processing were planned and implemented by Gia Lamela and W. Joseph Rhea. Jeff Bowles and Mary Kappus calibrated and flew the PHILLS sensor, and W.J. Rhea and J. Bowles solved the imaging GPS geo-referencing process. Re-calibration efforts are currently being lead by C. Davis and J. Bowles.

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